

The Galactic Sky seen by H.E.S.S.

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Abstract

The H.E.S.S. experiment is an array of four imaging Cherenkov telescopes located in the Khomas Highlands of Namibia. It has been operating in its full configuration since December 2003 and detects very-high-energy (VHE) γ rays ranging from 100 GeV to ~ 50 TeV. Since 2004, the continuous observation of the Galactic Plane by the H.E.S.S. array of telescopes has yielded the discovery of more than 50 sources, belonging to the classes of pulsar wind nebulae (PWN), supernova remnants (SNR), γ ray binaries and, more recently, a stellar cluster and molecular clouds in the vicinity of shell-type SNRs. Galactic emission seen by H.E.S.S. and its implications for particle acceleration in our Galaxy are discussed.

Keywords: Gamma-ray astronomy, Imaging Atmospheric Telescopes, H.E.S.S., Supernova Remnants, Binary Systems, Pulsar Wind Nebulae, Stellar Clusters

1. Introduction

In the last decade, the third generation of imaging atmospheric Cherenkov telescope (H.E.S.S., VERITAS, MAGIC and CANGAROO-III) came into operation and opened up a previously largely unexplored window on the very-high-energy (VHE) Universe. Since the pioneering Whipple experiment in 1989, the sensitivity has been increased by a factor of 100, leading to a detection time of ~ 25 s for a source of the intensity of the Crab

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Nebula compared to 50 h for the original detection (Weekes et al., 1989). The TeV source catalogue now comprises more than 100 sources¹. This scientific breakthrough was made possible by the combination of telescopes with large mirrors, cameras with fast photo-detectors and fine pixelation and the stereoscopic observation technique which, by combining several views of the same shower seen from different telescopes, allows a simple geometric reconstruction of the direction of the primary gamma ray and a significant improvement of the angular resolution and rejection capabilities. The High Energy Stereoscopic System (H.E.S.S.), an array of four imaging atmospheric Cherenkov telescopes situated in the Khomas Highland of Namibia (Aharonian et al., 2006a), played a major role in the opening up of this field, with in particular a very successful systematic survey of the inner parts of the Galactic Plane starting in 2004 and extended continuously since then (Aharonian et al., 2005b, 2006b; Chaves, 2009). The angular resolution of H.E.S.S. is better than 0.1° at all the accessible energies from ~ 120 GeV to several tens of TeV and the energy resolution is about 15% for a threshold varying from ~ 120 GeV at zenith to about 700 GeV at a zenith angle of 60° . The sensitivity of the H.E.S.S. instrument was recently improved by a factor of ~ 2 by the development of more sophisticated analysis techniques (Ohm et al., 2009b; Dubois et al., 2009; de Naurois & Rolland, 2009; Naumann-Godó et al., 2009; Fiasson et al., 2010), some of which also yielded an angular resolution improved by about 30%.

The H.E.S.S. Galactic Plane survey now covers most of the Galactic Plane as seen from the Southern Hemisphere, and led to the discovery of a rich population of more than 50 Galactic sources, belonging to the classes of pulsar wind nebulae (PWN), supernova remnants (SNR), γ ray binaries and, more recently, stellar clusters and molecular clouds in the vicinity of shell-type SNRs.

Outside of the Galactic Plane, more than 30 point-like sources have been discovered and associated with active galactic nuclei (AGN), mostly objects of the BL Lacertae type (BL Lac).

2. Survey of the Galactic Plane

The H.E.S.S. Galactic Plane survey (GPS) has been a core component of the observation program since 2004. The original GPS (Aharonian et al.,

¹See TeVCat, an online TeV γ -ray catalog, at <http://tevcat.uchicago.edu/>

2005b), consisting of ~ 230 h of observation after standard run-quality selection, covered the inner part of the Galaxy, from the Norma to the Scutum-Crux spiral arms tangent ($l \pm 30^\circ$ in longitude and $b \pm 3^\circ$ in latitude). It resulted in the firm discovery of eight previously unknown sources of VHE γ rays with a statistical significance above 6σ (post-trials²) and six likely sources above 4σ , all of them confirmed by subsequent deeper observations.

Between 2005 and 2009, the GPS was extended significantly in longitude, from $l \sim -60^\circ$ to $l \sim 275^\circ$ (Chaves, 2009). In addition, the overall exposure along the Galactic Plane was significantly increased with more than 1400 hours of accumulated data (representing roughly one third of the total H.E.S.S. data set). The H.E.S.S. exposure inside the Galactic Plane varies from a few hours on the less observed area to more than 100 hours in the deep exposure regions centered around targets of specific interest such as Sgr A*, RX J1713.7-3946, or LS 5039, leading to a sensitivity varying between less than 1% to about 10% of the Crab Nebula flux.

The pre-trials significance map of the Galactic Plane, reproduced from Chaves (2009) and calculated using the ring-background subtraction technique (Aharonian et al., 2006a) and *hard* cuts, is shown in Fig 1. A total of 56 Galactic sources are detected in the GPS. The major population consists of PWN (29 identified sources) followed by SNR (9 associations) and binary systems (3 systems).

Most of the Galactic VHE sources are found to be significantly extended, with sizes greater than the $\sim 0.1^\circ$ H.E.S.S. point spread function (PSF). The few sources in the Galactic Plane that appear point-like are associated with young pulsar wind nebulae (PWN), including the Crab Nebula (Aharonian et al., 2006a), or with VHE γ ray emitting high-mass X-ray binaries (HMXB) which include the very well established binaries PSR B1259-63 (Aharonian et al., 2005d) and LS 5039 (Aharonian et al., 2005c). The point-like VHE source HESS J0632+057 is now a strong candidate for a HMXB system following a recent multi-wavelength campaign (Aharonian et al., 2007c; Hinton et al., 2009).

After excluding five sources well off the Galactic Plane, with $|b| > 2^\circ$ (HESS J1356-645, HESS J1442-624, HESS J1507-662, HESS J1514-591, and

²Since the GPS contains a large number of test positions, the significance has to be corrected according to a “trial factor.” This trial factor accounts for the increased probability of finding a fake signal with an increased number of test positions for which a significance is calculated. A Monte Carlo simulation is used to correct for the number of trials.

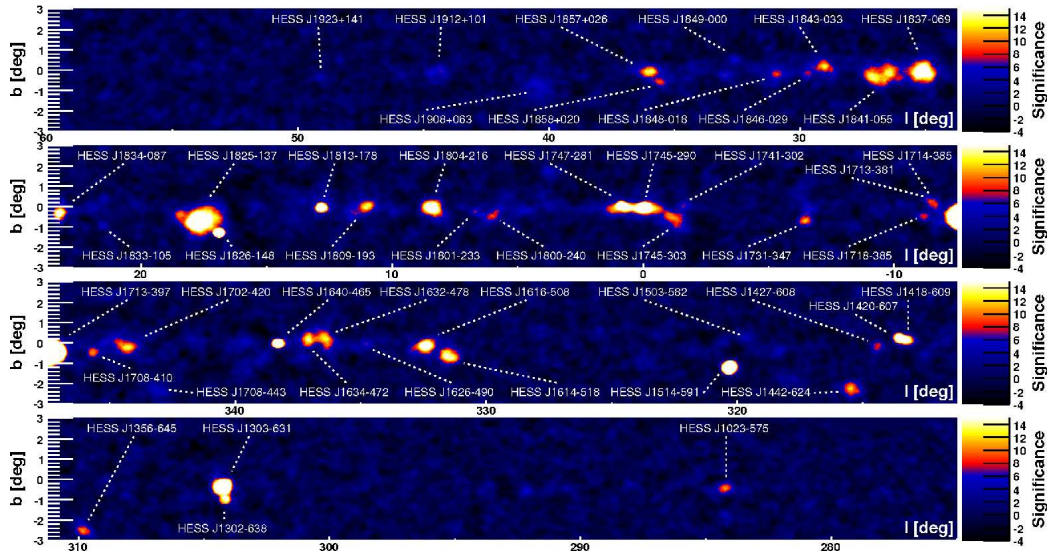


Figure 1: Pre-trial significance in the H.E.S.S. Galactic Plane Survey. Significance is truncated above 15σ to increase visibility. Figure reproduced from Chaves (2009).

SN 1006), the latitude distribution of the Galactic sources is very narrow ($\langle b \rangle = -0.26^\circ$ with an RMS of 0.40°). This scale is significantly smaller than the width of the region of significant H.E.S.S. exposure (of the order of $\sim 2^\circ$ in RMS), and similar to the scale of the molecular gas distribution. The latitude distribution is, at the first glance, compatible with what is the presumably parent populations of SNRs (Green, 2004) and high spin-down luminosity pulsars ($\dot{E} > 10^{34}$ ergs s^{-1}) from Manchester et al. (2005).

3. Supernova Remnants

Expanding shock waves in SNRs are believed to be able to accelerate cosmic rays (CR) up to multi-TeV energies through the mechanism of diffusive shock acceleration (DSA) (e.g. Drury, 1983). Moreover it was realized very early that, if a fraction of about 10% of their explosion energy is converted into cosmic rays, SNRs are capable of maintaining the galactic CR flux at the observed level (Baade & Zwicky, 1934). Most shell-type SNRs are non-thermal radio emitters, confirming that electrons are accelerated up to at least GeV energies. For a recent review on diffusive shock acceleration in the context of SNRs, see e.g. Hillas (2005).

Four shell-like SNRs with clear shell-type morphology resolved in VHE γ rays have been detected by H.E.S.S., allowing direct investigation of the SNRs as sources of cosmic rays. They are all remnants of recent supernovae (less than a few kyr): RX J1713.7-3946 (Aharonian et al., 2004, 2007b), RX J0852.04622 - also known as Vela Junior - (Aharonian et al., 2005f), SN 1006 (Acero et al., 2010) and HESS J1731-347 (Acero et al., 2009). A fifth case, RCW 86 (Aharonian et al., 2009b), might be added to this list although the TeV shell morphology has not yet been clearly proved.

All of them show a very clear correlation between non-thermal X-ray emission and VHE γ rays emission.

3.1. Probing the acceleration mechanisms

Amongst the aforementioned SNRs, SN 1006 is, due to its position 500 pc above the Galactic Plane, an ideal case to study particle acceleration mechanisms. It indeed expands into a relatively uniform, low density ($n \sim 0.085 \text{ cm}^{-3}$) medium (Acero et al., 2007; Katsuda et al., 2009) and uniform magnetic field. Moreover, SN 1006 is one of the best-observed SNRs with a rich data-set of radio, X-ray and optical measurements. The progenitor of SN 1006 is believed to be a type Ia supernova (Schaefer, 1996), probably the brightest supernova in recorded history. SN 1006 was detected by H.E.S.S. after a deep observation (130 h of data) and clearly exhibits a bipolar morphology (Fig. 2), strongly correlated with the non-thermal emission measured by XMM-Newton (Rothenflug et al., 2004).

The close correlation between X-ray and VHE-emission demonstrated by the radial profile (Fig. 3) points toward particle acceleration in the strong shocks revealed by the Chandra observation of X-ray filaments (Bamba et al., 2003). Moreover, the bipolar morphology of the VHE emission in the NE and SW regions of the remnant supports a major result of diffusive shock acceleration theory, according to which efficient downstream injection of suprathermal charged nuclear ions is only possible for sufficiently small angles between the ambient magnetic field and shock normal. Assuming a relatively uniform magnetic field oriented in the NE-SW direction, a higher density of accelerated nuclei at the poles is predicted (Ellison et al., 1995; Malkov & Voelk, 1995; Völk et al., 2003).

Three different models were investigated to account for the spectral energy distribution (SED), and are compared in Fig. 4. In a purely leptonic model (dotted blue line), TeV emission results from inverse-Compton scattering of multi-TeV electrons. The resulting magnetic field then needs to be higher

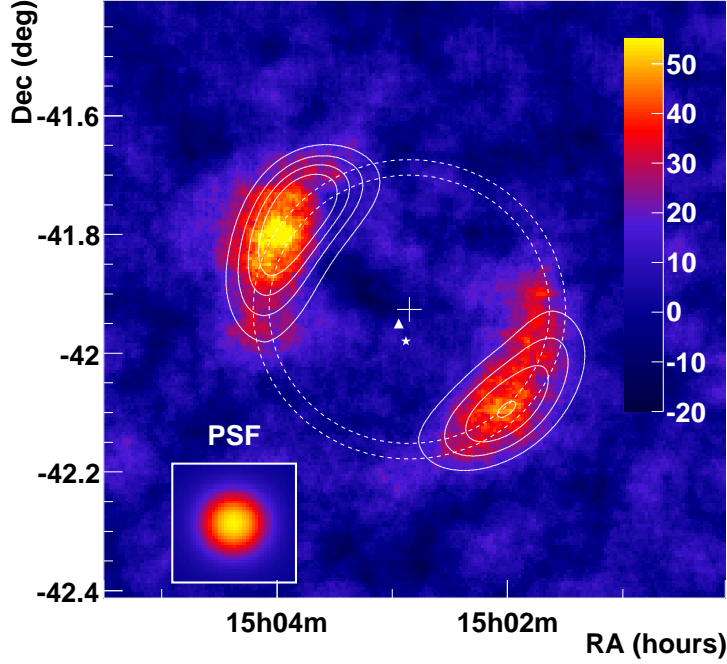


Figure 2: HESS γ rays correlated excess map of SN 1006. The linear colour scale is in units of excess counts per $\pi \times (0.05^\circ)^2$. The white contours correspond to a constant X-ray intensity as derived from the XMM-Newton flux map and smoothed to the H.E.S.S. point spread function, enclosing respectively 80% , 60% , 40% and 20% of the X-ray emission. Reproduced from Acero et al. (2010).

than $30 \mu\text{G}$ so that the IC emission does not exceed the measured VHE-flux. In a second, dominantly hadronic model (dashed red line), TeV emission results from proton-proton interactions with π^0 -production and subsequent decay, whereas the X-ray emission is still produced by leptonic interactions. The resulting magnetic field needs to be higher ($\sim 120 \mu\text{G}$), which is consistent with magnetic field amplification at the shock, as indicated by the measurements of thin X-ray filaments mentioned above, but requires that a very high fraction (about 20%) of the supernova energy was converted into high-energy protons to account for the TeV emission. A mixed model (solid black line), in which hadronic and leptonic processes contribute almost equally to the very high-energy emission, gives a good description of data,

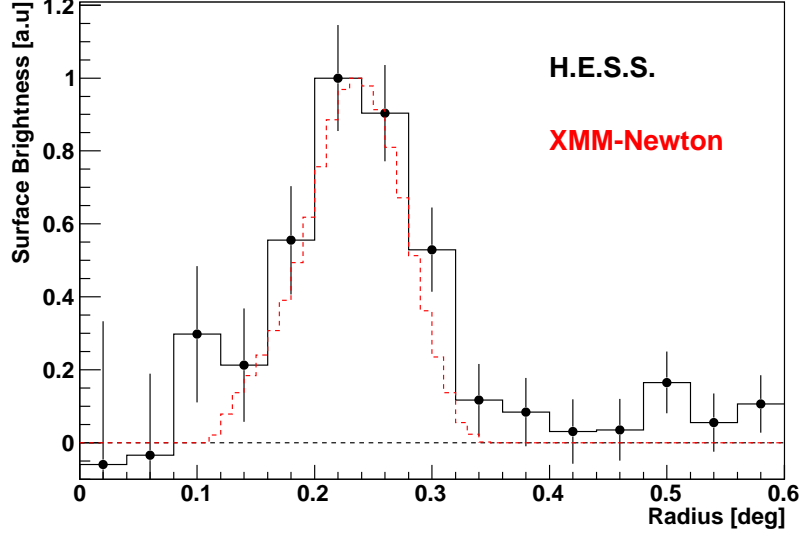


Figure 3: Radial profile around the centre of the SNR obtained from H.E.S.S. data and XMM-Newton data in the 2 - 4.5 keV energy band smoothed to H.E.S.S. . PSF. Reproduced from Acero et al. (2010).

with a more reasonable overall acceleration efficiency of $\sim 12\%$. Discrimination between the different models might be possible from observations in the MeV domain, however no instrument with the required sensitivity is currently in operation.

3.2. Measurements of acceleration efficiency and magnetic fields

The efficiency of particle acceleration in SNRs is an essential element to understand whether SNRs can account for the observed level of CRs in the Galaxy. Elaborated, explicitly time-dependent, nonlinear kinetic models of cosmic ray (CR) acceleration in SNRs (e.g. Berezhko et al., 2009) predict significant retroaction of the accelerated particles on the shock structure (Berezhko & Ellison, 1999) and result in magnetic field amplification. Recent measurements using thermal Doppler broadening of the $H\alpha$ line on RCW 86 (Helder et al., 2009) indicate that the postshock temperature is very significantly lower ($2.3 \pm 0.3\text{keV}$) than previously expected from the measured shock velocity ($42 - 70\text{keV}$). This was attributed to a large acceleration efficiency, resulting in a cosmic-ray induced pressure that can exceed the thermal

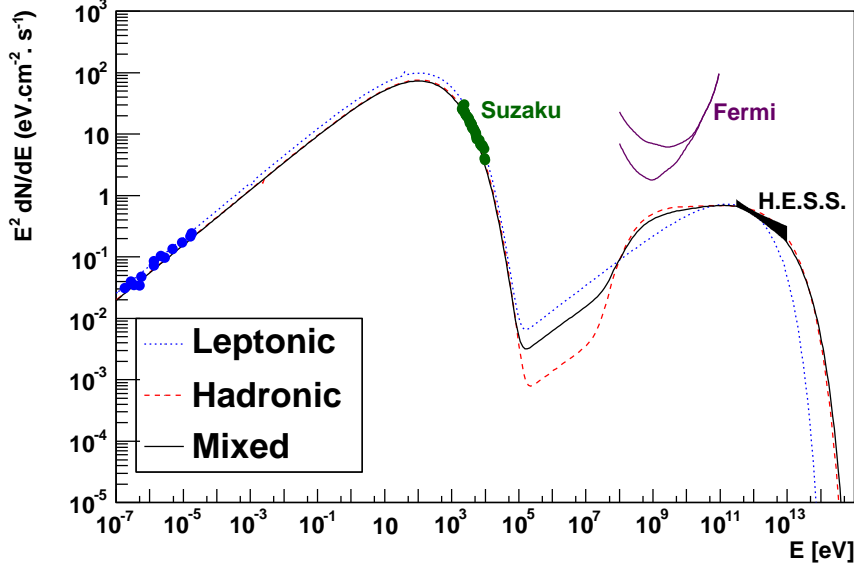


Figure 4: Spectral Energy Distribution predicted for SN 1006 for three different emission models: a purely leptonic model (dotted blue line), an hadronic model (dashed red line) and a mixed model (solid black line).

pressure behind the shock.

In the last years, a growing consensus toward evidence for magnetic field amplification in the shocks of SNRs has emerged. Measurements of thin filaments in SN 1006 with Chandra (Berezhko et al., 2003; Bamba et al., 2003) strongly suggest rapid electron cooling in intensified magnetific fields of the order of 0.1 mG, although they do not exclude alternate possible explanations such as field damping. More recently, the discovery of the brightening and decay of X-ray hot spots in the shell of the SNR RXJ1713.7-3946 on a one-year timescale (Uchiyama et al., 2007) indicates magnetic field amplification factors of the order of 100.

In summary, young supernova remnant have been proved to accelerate particles (electrons and/or protons) up to 100 TeV at least. γ rays emission at 100 TeV is difficult to achieve with inverse-Compton scattering due to Klein Nishina suppression of the cross section at high energies. Moreover, there is growing evidence that the efficiency can be as large as 50% due to the retroaction of cosmic rays on the shock. Magnetic field amplification, predicted in

the framework of DSA, is now convincingly observed in several objects, thus further supporting the hypothesis of hadron acceleration in SNRs. The debate remains inconclusive however, with comprehensive time-dependent models based on non-linear diffusive shock acceleration such as that of Morlino et al. (2009) arguing strongly in favor of hadronic acceleration, whereas other authors (Ellison et al., 2010), using a consistent calculation of thermal X-ray emission, predict very intense X-ray thermal bremsstrahlung emission in the hadronic scenario, in contradiction with observations.

3.3. Gamma-ray emission from illuminated clouds

Further insight into the acceleration mechanisms in SNRs can come from the observation of middle-aged supernova remnants in the vicinity of dense molecular clouds (Gabici et al., 2009). Indeed, production of γ rays is expected both during the acceleration phase of cosmic rays in the SNR shock and during their subsequent propagation. Molecular clouds can act as cosmic-ray barometers, with an enhanced γ ray emission proportional to the cloud mass, whereas inverse-Compton emission from accelerated electrons would not be enhanced. Furthermore, the γ ray emission from a cloud depends on the propagation time and can therefore last much longer than the emission from the SNR, making the detection of clouds more probable (Gabici & Aharonian, 2007). A specific spectral signature, in the form of a concave energy spectrum, has been predicted by Gabici et al. (2009) but not observed so far.

Four old SNRs in the vicinity of molecular clouds have been detected by H.E.S.S.: W 28 (Aharonian et al., 2008d), an old ($\sim 35 - 150$ kyr) mixed-morphology SNR, HESS J1745-303 (Aharonian et al., 2008a), HESS J1714-385 (Aharonian et al., 2008c) and more recently HESS J1923+141 (Fiascon et al., 2009). In W 28, H.E.S.S. data show VHE emission from four different spots coincident with HII regions and dense molecular clouds revealed by NAN-TEN $^{12}\text{CO}(J = 1 - 0)$ data (Mizuno & Fukui, 2004). Interaction with a molecular cloud along its north and northeastern boundaries is further confirmed by the high concentration of 1720 MHz OH masers (Claussen et al., 1997). Under the assumption of cloud distance between 2 and 4 kpc, a cosmic-ray overdensity in the range 13 to 32 is derived, which is consistent with expectations.

Similar conclusions are derived from observations of HESS J1745-303, HESS J1714-385 and HESS J1923+141, thus confirming that shell-type SNRs are efficient accelerators of hadronic cosmic rays. Three of these old SNRs in the vicinity of clouds are firmly associated with bright Fermi sources

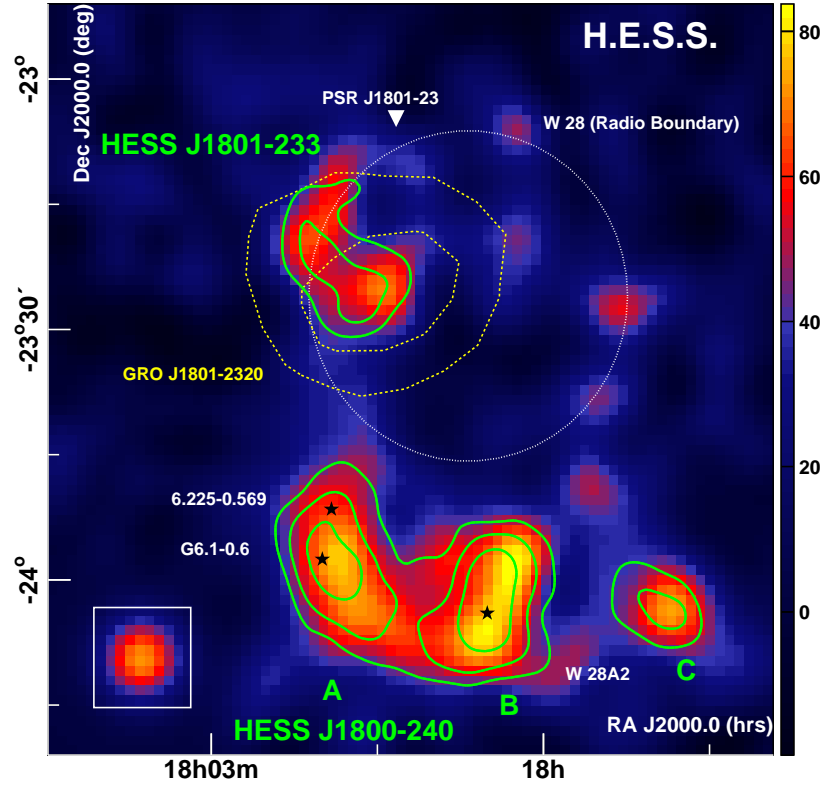


Figure 5: Image ($1.5^\circ \times 1.5^\circ$) of the VHE γ -ray excess counts (events), corrected for exposure and smoothed with a Gaussian of radius $4.2'$ (standard deviation). Overlaid are solid green contours of VHE excess (pre-trial) significance levels of 4 , 5 , and 6σ , after integrating events within an oversampling radius $\theta=0.1^\circ$ appropriate for pointlike sources. From (Aharonian et al., 2008d).

(Abdo et al., 2009a): W 28 is associated with 1FGL J1801.3-2322c and 1FGL J1800.5-2359c, HESS J1714-385 is associated with 1FGL J1714.5-3830 and HESS J1923+141 with 0FGL J1923.0+1411. A possible, less convincing, association also exists for HESS J1804-216. Spectral continuity between GeV and TeV energies, large cosmic-ray densities derived from the VHE flux and coincidence with the shocked clouds strongly favours a hadronic origin of the GeV and TeV γ rays.

Further multiwavelength studies with ACTs and Fermi will help to understand the mechanisms at the origin of Galactic CRs.

4. Pulsar Wind Nebulae

Nearly half of the Galactic VHE sources, starting from the famous Crab Nebula (Weekes et al., 1989) are associated with young, energetic pulsars. These sources exhibit strong ultra-relativistic winds of particles that lead to the formation of a synchrotron nebula when the winds interact with the surrounding medium. Strong shocks are formed, resulting in acceleration of particles up to hundreds of TeV.

H.E.S.S. has detected a wide range of PWNs. Young PWNs such as the Crab Nebula (Aharonian et al., 2006a), SNR G 0.9+0.1 (Aharonian et al., 2005a), SNR G 21.5-0.9 (Djannati-Atai et al., 2007), Kes 75 (Terrier et al., 2008), MSH 15-52 (Aharonian et al., 2005e) and HESS J1813-178 (Aharonian et al., 2006b; Gotthelf & Halpern, 2009) are generally compact and unresolved. In such systems, VHE emission is generally attributed to inverse-Compton scattering of 1 – 100 TeV electrons (e.g. Atoyan & Aharonian, 1996). Statistical studies (Wenig et al., 2008) indicate that the majority, if not all, of young high-spindown luminosity pulsars produce significant TeV emission.

Older PWNs such as HESS J1825-137 (Aharonian et al., 2006c) and HESS J1303-631 (Dalton et al., 2009) show more complex morphologies, with significant offsets between the pulsar and the nebula. Spectral steepening away from the pulsar, detected in HESS J1825-137 (Fig. 6 and 7, is the first direct evidence of radiative cooling of electrons. VHE-emitting electrons are usually less energetic than those emitting X-rays, do not suffer from severe radiative losses and therefore can survive in greater number from the early epoches of the PWN evolution. The high VHE luminosity of HESS J1825-137 compared to the X-ray luminosity can be explained by a significant contribution of ‘relic’ electrons released in the early history of the pulsar, when the spin-down luminosity was higher. The variation of index with distance from the

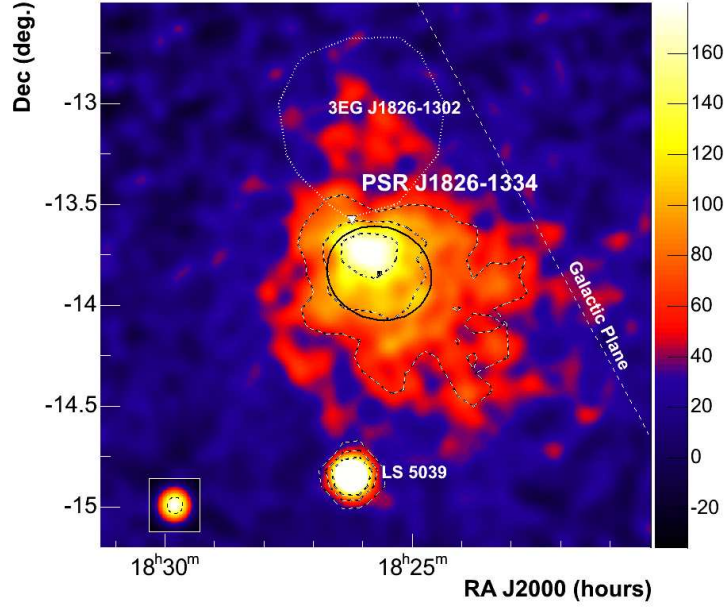


Figure 6: Acceptance-corrected smoothed excess map (smoothing radius $2.5'$) of the $2.7^\circ \times 2.7^\circ$ field of view surrounding HESS J1825-137. From Aharonian et al. (2006c).

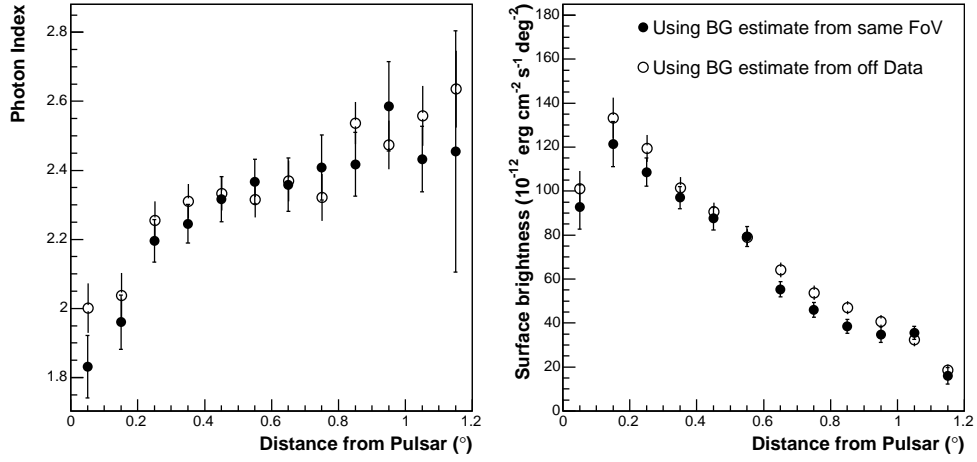


Figure 7: Energy spectra of HESS J1825-137 in radial bins. **Left:** Power-law photon index as a function of the radius of the region (with respect to the pulsar position). **Right:** Surface brightness between 0.25 and 10 TeV per integration region area in units of $10^{-12} \text{ erg cm}^{-2} \text{ s}^{-1} \text{ deg}^{-2}$ as a function of the distance to the pulsar position.

pulsar is attributed both to inverse-Compton and synchrotron cooling of the continuously accelerated electrons. Further confirmation of this mechanism is required from observation of other old PWNs and may arise from HESS J1303-631. Recently, the first extragalactic PWN was detected in the Large Magellanic Cloud (Komin et al., 2009).

5. Dark Accelerators

About half of the Galactic VHE sources show no clear counterparts in lower-energy wavebands and remain unidentified (Aharonian et al., 2008b; Tibolla et al., 2009), a fraction similar to that observed with EGRET (Hartman et al., 1999) and now with Fermi (Abdo et al., 2009a). The vast majority of these sources are significantly extended, well beyond the PSF of H.E.S.S.. Understanding the emission mechanism powering these sources is a challenge of multi-wavelength astronomy.

It has been recently suggested (de Jager et al., 2009) that a significant fraction of these sources could be old pulsar wind nebulae in a late evolution stage. Indeed, magneto-hydrodynamic simulations indicate that the magnetic field in PWN decreases with time as $t^{-1/3}$, leading to the extinction of the synchrotron emission. In contrast, the inverse-Compton emission tends to increase with time until most of the pulsar spindown power has been dumped into the nebula.

Alternate models include, in particular, emission from molecular clouds illuminated by cosmic rays coming from a nearby source (Aharonian & Atoyan, 1996; Gabici et al., 2009), in which a concave energy spectrum would constitute a definitive proof.

6. Binary Systems

X-ray binaries (XRBs) comprise a compact object such as a neutron star or black hole orbiting around a companion star. They are one of several types of astrophysical systems that provide an environment in which the acceleration of particles and subsequent production of radiation might be periodic. Modulation of this radiation, linked to the orbital motion of the binary system, provides key insights into the nature and location of particle acceleration and emission processes.

LS 5039 is one of the handful of X-ray binaries that have been detected at VHE γ rays (Aharonian et al., 2005c). Results from 70 hr of observations

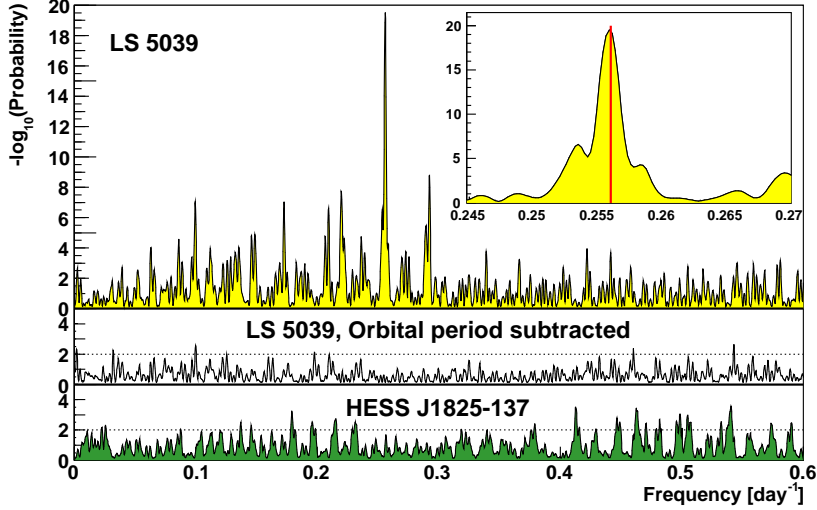


Figure 8: **Top:** Lomb-Scargle (LS) periodogram of the VHE runwise flux for LS 5039 (chance probability to obtain the LS power vs. frequency). Inset: zoom around the highest peak (pre-trial probability $\sim 10^{-20}$), which corresponds to a period of 3.9078 ± 0.0015 days. **Middle:** LS periodogram of the same data after subtraction of a pure sinusoidal component at the orbital period of 3.90603 days. **Bottom:** LS periodogram of the HESS source HESS J1825–137 observed simultaneously in the same field of view. From Aharonian et al. (2005c)

distributed over many orbital cycles yielded a modulation of the VHE γ ray flux (> 100 GeV) with a period of 3.9078 ± 0.0015 days (Aharonian et al., 2006d), consistent with the orbital period reported by Casares et al. (2005). The corresponding H.E.S.S. Lomb-Scargle periodogram is shown in Fig. 8.

Orbital modulation of the VHE spectrum, shown in Fig. 9, was interpreted as the result of phase-dependent pair creation on the stellar photon field (e.g. Maraschi & Treves, 1981; Dubus, 2006), leading to a significant absorption of the VHE flux at the superior conjunction (in blue on Fig. 9), when the compact object is behind the star.

Recent observations with Fermi (Abdo et al., 2009b) yielding a consistent period of 3.903 ± 0.005 days in GeV γ rays, with the maximum of the GeV emission during the superior conjunction, when the TeV flux is at its minimum and vice-versa (Fig. 9). This clear anticorrelation, predicted in inverse-Compton scattering models (e.g. Dubus et al., 2008; Cerutti et al., 2008), results from the competition of the inverse-Compton and pair-creation pro-

cesses: The inverse-Compton emission in the MeV-GeV regime is enhanced when the highly-relativistic electrons seen by the observer encounter the seed photons head-on (at superior conjunction) while VHE absorption due to pair production is maximum at the same position leading to suppression of VHE photons.

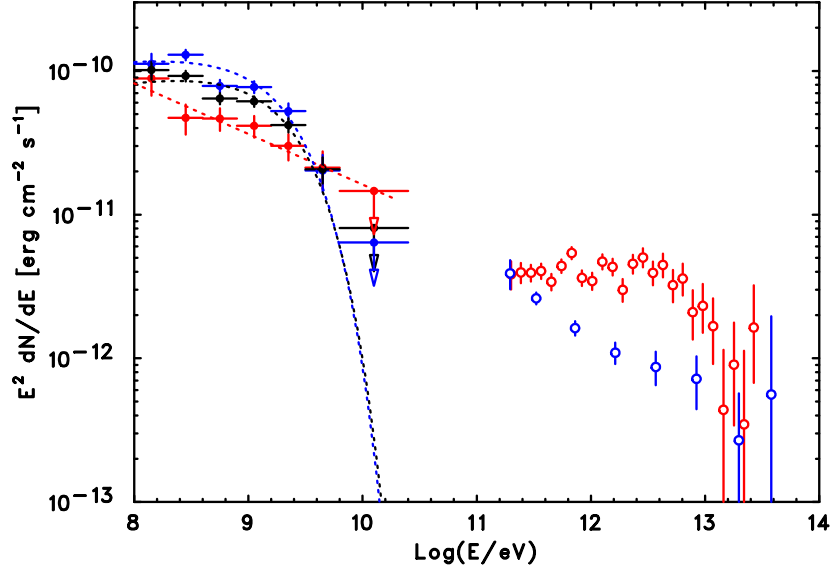


Figure 9: Phase resolved SED of LS 5039 with Fermi and H.E.S.S. . The black points (dotted line) represent the phase-averaged Fermi/LAT spectrum. The red data points (dotted line) represent the spectrum (overall fit) at inferior conjunction (Phase 0.45–0.9); blue data points (dotted line) represent the spectrum (overall fit) at superior conjunction (Phases, < 0.45 and > 0.9). From Abdo et al. (2009b)

After the discovery of the binary pulsar PSR B1259-63 by H.E.S.S. (Aharonian et al., 2005d, 2009a) and LS I +61 303 by MAGIC (Albert et al., 2008), a H.E.S.S. unidentified source, HESS J0632+057 has been recently added to the list of γ ray binary candidates. (Aharonian et al., 2007c; Hinton et al., 2009).

7. Massive Star Clusters

Since they host supernova remnants and pulsar wind nebulae, massive stellar clusters are obviously potential acceleration sites of VHE particles, but several alternate scenarios also provide plausible explanations for the production of VHE particles.

Many stellar clusters harbor massive stars frequently bound in multiple star systems. The strong and fast winds from a collision region where particles can be accelerated up to γ ray energies (e.g. Eichler & Usov, 1993). Acceleration models involve either leptonic processes (inverse-Compton scattering) or hadronic processes (inelastic scattering of nucleons in the dense stellar wind followed by production of neutral pions which subsequently decay into VHE γ rays).

In addition, the strong stellar winds of individual massive stars also interact with each other and lead to the formation of wind-blown bubbles, filled with a low-density hot plasma (Voelk & Forman, 1982) in which diffusive shock acceleration can take place. (Klepach et al., 2000; Bykov, 2001; Parizot et al., 2004; Higdon & Lingenfelter, 2005; Dwarkadas, 2008).

VHE γ ray excess emission towards (at least) two massive star clusters has been detected: Westerlund 1 (Ohm et al., 2009a), the most massive cluster in our Galaxy, and Westerlund 2 (Aharonian et al., 2007a; Abramowski et al., 2011). In addition, two unidentified H.E.S.S. sources, HESS J1614-581 and HESS J1848-018, may be related to similar systems (Ohm et al., 2010).

Westerlund 1 harbors at least 24 Wolf-Rayet stars of which $> 70\%$ are in binary systems (Groh et al., 2006), in addition to blue and red super-giants stars. This makes the collective winds scenario quite attractive.

In the Westerlund 2 region, the prominent binary system WR20a, including its colliding wind zone (e.g. Bednarek, 2005), would appear as a point source for observations with the H.E.S.S. telescope array. After detection of extended VHE γ ray emission and apparent lack of flux variability over orbital timescales, alternative mechanisms involving collective stellar wind effects are preferred. Furthermore, the recent discovery of two neighboring bright pulsars 1FGL J1023.0 5746 and 1FGL J1028.4 5810 by the Fermi collaboration (Abdo et al., 2009c) motivated again the consideration of the pulsar wind nebula emission.

The connection with collective stellar wind emission hypothesis appears quite attractive in these systems, in particular due to the extension of the VHE emission, but needs to be confirmed through further observations in the H.E.S.S. energy band and by considering the full MWL perspective. Unique signatures, such as energy dependent morphology changes or MWL correlation (or anticorrelation) with the VHE emission are still needed to unequivocally confirm the connection to wind-related phenomena in massive star clusters.

8. Conclusions

The results presented here represent only a subset of the discoveries made by the ground based γ ray astronomy, and in particular by H.E.S.S. during the last years. Other significant results from H.E.S.S. , regarding in particular extragalactic sources of VHE γ rays, include amongst others observation of fast variability and giant flares in active galactic nuclei, detection of starburst galaxies or search of dark matter annihilation in gravitational potential wells.

In 2012, the H.E.S.S. array will be completed with the addition of a very large telescope (28 m diameter) in the centre of the present array. An energy threshold of 30 GeV is expected from this large telescope in stand-alone mode. Stereoscopy including the very large telescope and at least one of the other four should allow for a threshold of 80 GeV with improved sensitivity. This new facility will provide a significant overlap between the energy ranges covered by γ ray satellites (Fermi-LAT and AGILE) and H.E.S.S., thus helping to understand the mechanisms at the origin of Galactic CRs.

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